InP MMIC Chip Set for Power Sources Covering 80-170 GHz

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ABSTRACT

We will present a Monolithic Millimeter-wave Integrated Circuit (MMIC) chip set which provides high output-power sources for driving diode frequency multipliers into the terahertz range. The chip set was fabricated at HRL Laboratories using a 0.1-μm gate-length InAlAs/InGaAs/InP high electron mobility transistor (HEMT) process, and features transistors with an f_{max} above 600 GHz. The HRL InP HEMT process has already demonstrated amplifiers in the 60-200 GHz range[1]. In this paper, these high frequency HEMTs form the basis for power sources up to 170 GHz.

A number of state-of-the-art InP HEMT MMICs will be presented. These include voltage-controlled and fixed-tuned oscillators, power amplifiers, and an active doubler. We will first discuss an 80 GHz voltage-controlled oscillator with 5 GHz of tunability and at least 17 mW of output power, as well as a 120 GHz oscillator providing 7 mW of output power. In addition, we will present results of a power amplifier which covers the full WR10 waveguide band (75-110 GHz), and provides 40-50 mW of output power. Furthermore, we will present an active doubler at 164 GHz providing 8% bandwidth, 3 mW of output power, and an unprecedented 2 dB of conversion loss for an InP HEMT MMIC at this frequency. Finally, we will demonstrate a power amplifier to cover 140-170 GHz with 15-25 mW of output power and 8 dB gain.

These components can form a power source in the 155-165 GHz range by cascading the 80 GHz oscillator, W-band power amplifier, 164 GHz active doubler and final 140-170 GHz power amplifier for a stable, compact local oscillator subsystem, which could be used for atmospheric science or astrophysics radiometers.

I. INTRODUCTION

The 140-170 GHz frequency range is interesting for atmospheric science heterodyne radiometers, as several molecular species radiate in that frequency regime, or a multiple of it. A harmonic mixer could make use of a direct local oscillator in the 140-170 GHz range, while a subharmonic mixer operating at 280 - 340 GHz or 560 – 680 GHz could be pumped with a 140-170 GHz LO, or such an LO followed by a doubler. Water has an important spectral line at 557 GHz, and is being studied in the future MIRO (Microwave Instrument for the Rosetta Orbiter) mission, using a heterodyne system with a Gunn oscillator operating at 140 GHz. An aircraft instrument, the Cloud-Ice Radiometer, seeks to study ice in clouds at different altitudes, and makes use of a heterodyne system with local oscillator at 162.5 GHz. Gunn oscillators are increasingly difficult to obtain commercially, and passive multipliers may not offer high enough output power to drive a mixer in a heterodyne receiver. This paper discusses an InP HEMT chip set fabricated at HRL Laboratories, LLC which could provide an alternative to passive components for a local oscillator source in the 140-170 GHz frequency range. All of the measurements discussed here were obtained on-wafer, using waveguide RF wafer probes [2].

II. OSCILLATORS

The first component of the chip set is an 80 GHz voltage controlled oscillator. Other oscillators in this frequency range are included in [3,4]. A photograph of the chip is shown at left in Figure 1. It consists of a 4×37 μm gate periphery HEMT device in a common source configuration. The series feedback element is a CPW transmission line at the source. The varactor element is the gate-source capacitance of a 4×25 μm gate

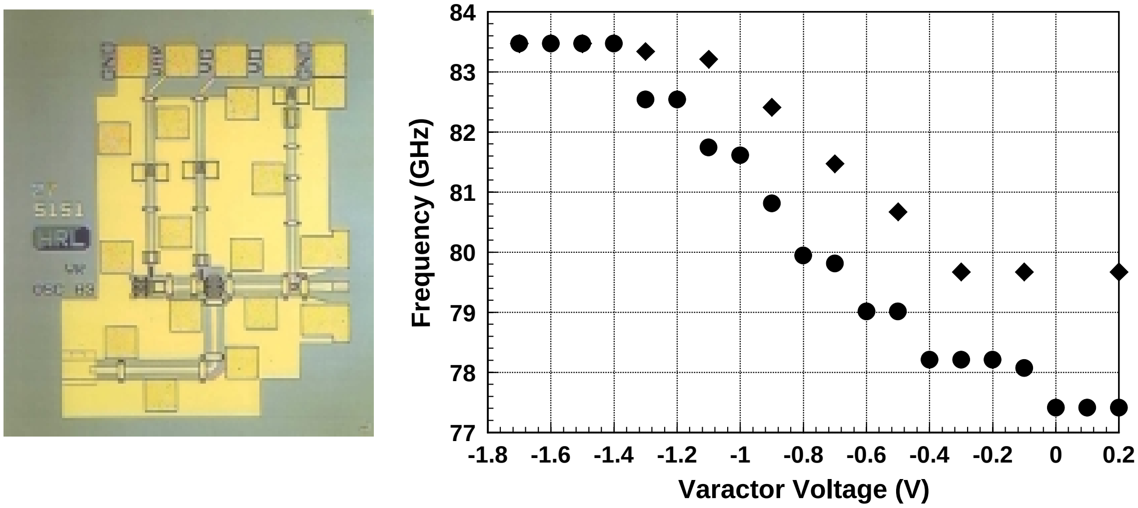

Figure 1. At left, the chip photograph of the 80 GHz VCO is shown. At right, the frequency tuning capability as a function of varactor control voltage is shown. The diamonds and circles represent two stable operating conditions of the VCO, depending on the direction of turning on the varactor voltage.

periphery HEMT, to the left of the larger a 4×37 μm gate periphery HEMT. The larger HEMT is used at the output to maximize output power. The varactor capacitance is varied by changing the gate supply voltage. The graph at right in Figure 1 shows that 6 GHz of tuning is obtained by changing the varactor voltage. The output power achieved between 77.5 and 83.5 GHz is 13 +/- 0.5 dBm. The chip measures 1.2 x 1.3 mm^2, and operates at a drain voltage of V_d=2.5 V and I_d= 30 mA.

A second, fixed-tuned oscillator was designed in addition to the 80 GHz VCO. This oscillator made used of a tuning stub with removable airbridges. Frequency of oscillation was measured by mixing the oscillator output with a Millitech 90 GHz Gunn oscillator. The mixer output was connected to a spectrum analyzer. Figure 2 shows the chip photograph at left. The circuit is biased at the drain voltage of 2.5 V, gate voltage Vg of -.036 V, and the drain current of 25 mA. With the airbridges on the chip intact, the oscillation frequency for this bias condition is 119.8 GHz. The output power at 119.8 GHz is 8.7 dBm, as measured with a WR8 Anritsu power meter. By scribing out the first airbridge, the frequency of oscillation changes to 129 GHz. Removal of the second airbridge results in a frequency of oscillation of 134 GHz. The output power as a function of frequency is shown in the graph at the right in Figure 2.

III. W-BAND AMPLIFIER

Amplification of the 80 GHz VCO may be required in order to drive an active doubler to 160 GHz. A suitable amplifier that could be used is the chip shown in Figure 3. This medium power amplifier makes use of 3 stages of a 4×37 μm gate periphery HEMT

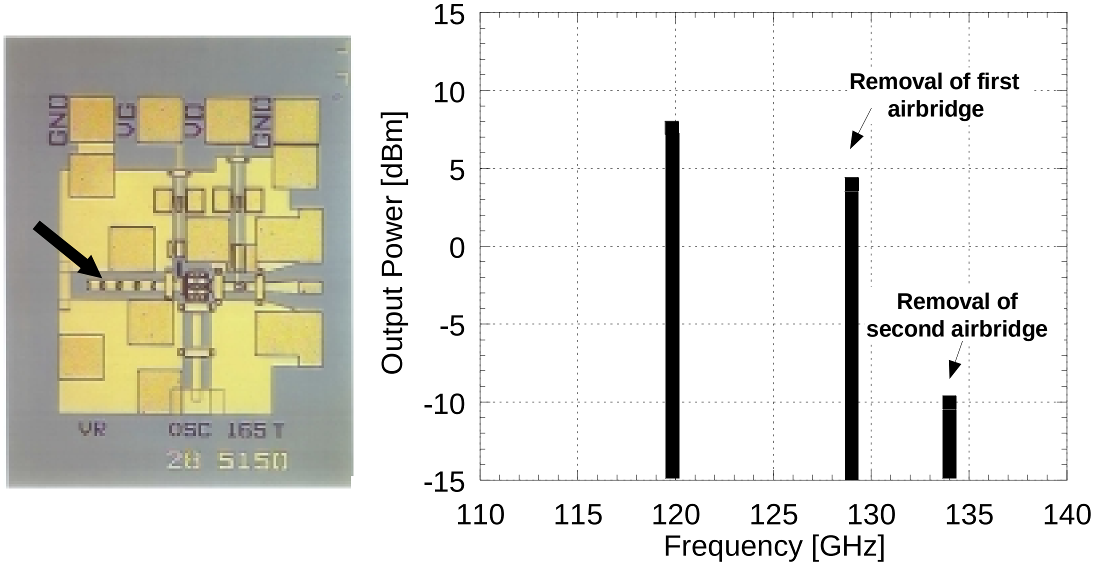

Figure 2. At left is the chip photograph of a 120 GHz fixed-tuned oscillator, showing the tuning stub in the left-center portion of the photograph (arrow). Removal of the first or second airbridge tunes the frequency according to the graph at right.

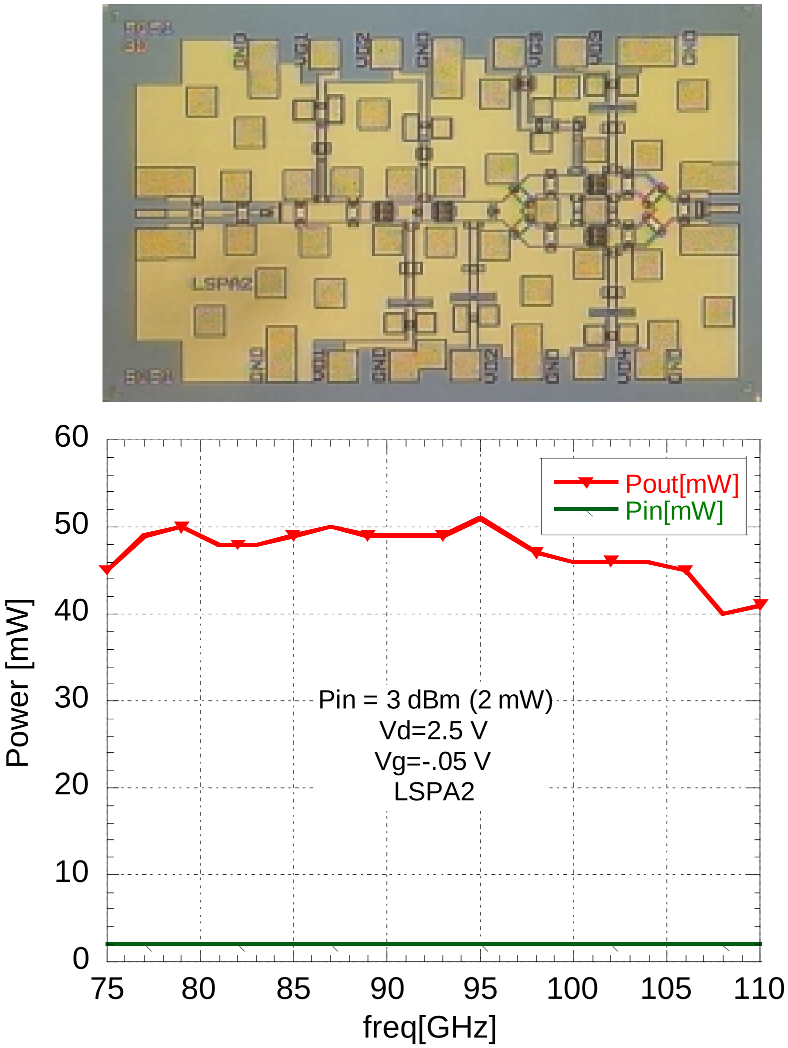

Figure 3. Chip photograph of the W-band power amplifier and output power as a function of frequency for a fixed input power of 2 mW.

devices, with two HEMTs combined in parallel in the last stage to maximize output power. A similar amplifier was described in [5], with 6 dB of large signal gain and at least 25 mW from 75-110 GHz. Our current amplifier was driven by a backward wave oscillator, and the output power was measured using an HP power meter equipped with a WR10 waveguide sensor. The amplifier exhibits 13 dB of large signal gain, and puts out 40-50 mW of output power over the 75-110 GHz WR10 waveguide band. Such an amplifier could find many uses for test equipment, or as a driver for active or passive frequency multipliers in a subsequent stage. The amplifier operates at 2.5 V, 250 mA, for a minimum power-added efficiency of 6%.

IV. ACTIVE DOUBLER

A class B doubler was designed using the harmonic balance simulator from Agilent’s Series IV. The matching elements are realized using grounded CPW lines. The fundamental frequency at the output is suppressed using a quarter-wave open stub, which presents a short at the fundamental and an open at the second harmonic. The highest frequency HEMT doubler previously reported is a 180 GHz MMIC with a 6 dB conversion loss at an input power of 0 dBm [6]. For comparison, a 94 GHz Schottky diode doubler demonstrated 6 dB conversion loss at 55 mW of output power[7].

Figure 4 shows a photograph of the fabricated MMIC doubler. The chip size is 1.1×1.2 mm^2. The doubler is biased at the pinchoff condition, with a gate voltage of –0.6 V. The drain voltage was 2.5 V. We measured the doubler on-wafer using a WR10 waveguide wafer probe at the input and a WR5 waveguide wafer probe at the output of the chip. The input was driven by a backward wave oscillator from 75-90 GHz. The output power was measured with a WR5 Anritsu power sensor. The best results were obtained at the input frequency of 82 GHz. The graph at right in Figure 4 shows the output power and conversion loss as a function of output frequency. A conversion loss of 2 dB is measured at an input power at 82 GHz of 7 dBm. This corresponds to an output power of 5 dBm or 3.2 mW at 164 GHz. The RF efficiency of this doubler is 63 %. The 3 dB bandwidth of this active doubler is approximately 158-173 GHz.

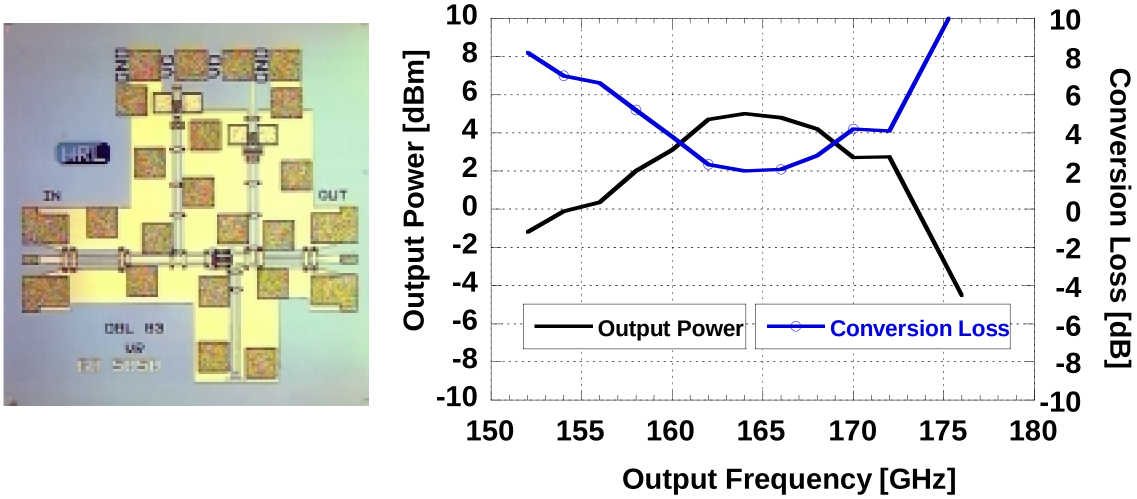

Figure 4. At left, the chip photograph of the 82-164 GHz active doubler is shown. At right, output power and conversion loss as a function of frequency are illustrated.

V. WR5 Power Amplifier

The final stage of our proposed local oscillator source is a power amplifier to amplify the active doubler of section IV. Figure 5 shows a photograph of the power amplifier. The chip features another grounded CPW design, with 3 stages of 4x37 micron gate periphery HEMTs. As in the W-band amplifier, two HEMTs were combined in the output stage to maximize output power. The chip size was 1.1 x 1.9 mm^2.

The power amplifier chip was first measured on-wafer for small signal S-parameters, using a WR5 waveguide frequency extender from Oleson Microwave Labs and an HP 8510A vector network analyzer. The amplifier exhibits 10 dB of small signal gain from approximately 144-170 GHz. The glitch around 143 GHz is a product of the measurement system. The input and output return losses are 10 dB at 165 GHz, and are shown in the middle graph of Figure 5. For these measurements, the chip was biased at Vd = 2.5 V, Id = 240 mA, and Vg = 0 V.

Power measurements on this chip were obtained using a WR10 BWO from 70-85 GHz to drive a Millitech doubler source between 140-170 GHz. The doubler was characterized for its output power using a WR5 Anritsu power meter, and then the BWO and doubler were connected to a WR5 RF wafer probe on the probe station. The power amp chip was biased with DC needle probes, and the output power as a function of frequency was measured again using the WR5 Anritsu power meter and a WR5 RF wafer probe.

The output power as a function of frequency and input power is shown for one of the power amp chips. The input power was varied to give the maximum output power. Peak power was observed at 150 GHz, with a maximum output power of 14.1 dBm or 25 mW, for an input power of 6.3 dBm, yielding a large signal gain of approximately 8 dB. From 140-170 GHz, 15 to 25 mW (11.8 – 14 dBm) of output power is achieved across the band. For the power measurements, a drain voltage of 2.1 V gave the optimized output power, for a drain current of 250 mA and a gate voltage of 0V. This amplifier could be a useful gain stage following the active doubler of the previous section. The power obtainable from the active doubler between 162-166 GHz was 5 dBm (refer to Figure 4). In Figure 5, the power out of the amplifier is at least 15 mW for an input power of 5 dBm (3.2 mW) for these frequencies.

VI. CONCLUSIONS

We have presented results of a chip set fabricated at HRL Laboratories, LLC using InP HEMTs which could form the local oscillator chain of a heterodyne receiver for atmospheric science or astrophysics radiometers. The resultant output power from such a chain could be as large as 15-20 mW from 158-166 GHz.

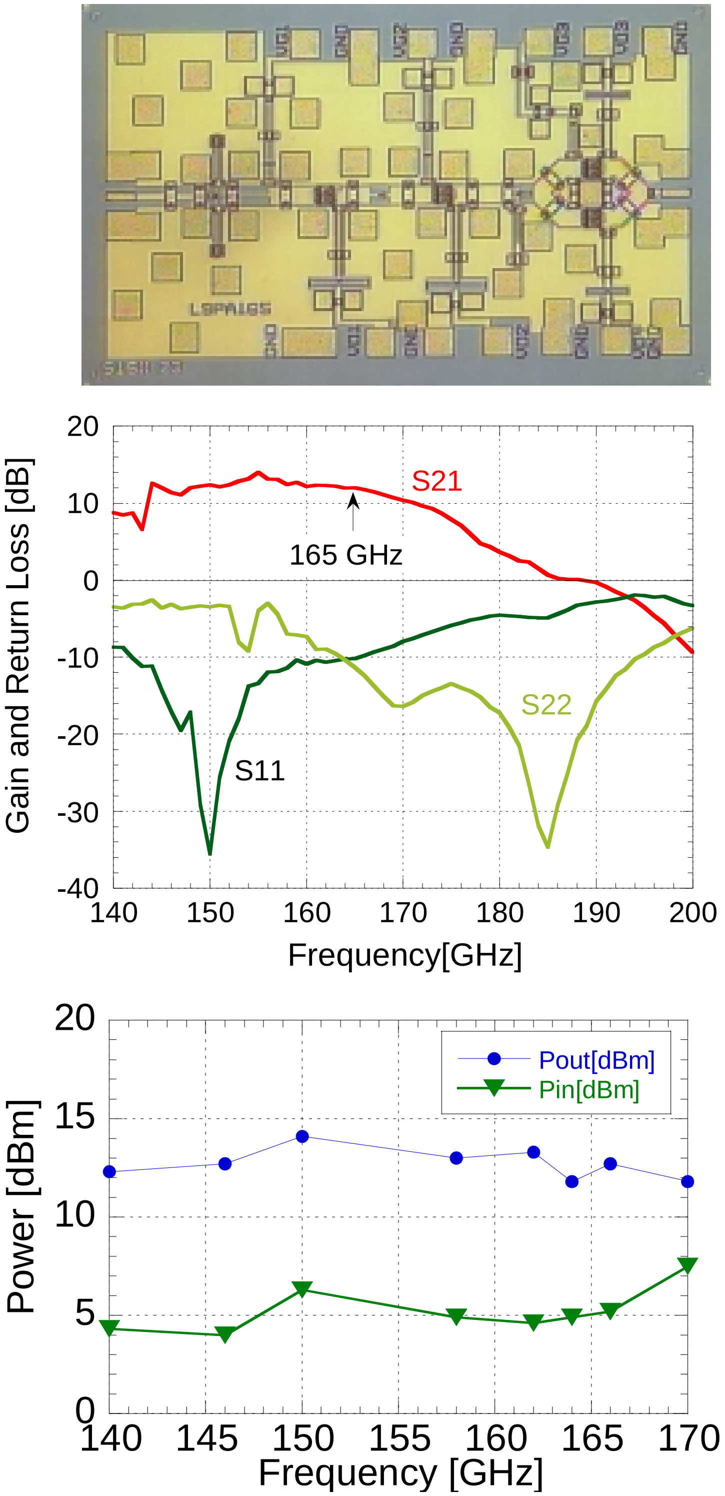

Figure 5. 140-170 GHz power amplifier chip (top photo), showing S-parameters (middle graph) and output power (lower graph) as a function of frequency.

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